

Comptonization of cosmic microwave background by cold ultra-relativistic electron-positron pulsar wind and origin of ~ 100 GeV lines

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Previously, [1] proposed an astrophysical explanation of narrow gamma-ray line-like feature(s) at ~ 100 GeV from Galactic Center region observed by Fermi/LAT [2]. The model of [1] is based on the inverse Compton scattering of external ultra-violet/X-ray radiation by a cold ultra-relativistic e^+e^- pulsar wind. We show that the extra broad ~ 30 MeV component should arise from Comptonization of cosmic microwave background radiation. We estimate the main parameters of this component and show that it can be detectable with MeV telescopes such as CGRO/COMPTEL. The location of CGRO/COMPTEL unidentified source GRO J1823-12 close to excess of 105-120 GeV emission (Reg. 1 of [2]) can be interpreted as an argument in favour of astrophysical model of the narrow feature(s) at ~ 100 GeV.

I. INTRODUCTION

Previous claims about the presence of narrow line-like γ -ray feature(s) around 100-130 GeV observed by Large Area Telescope (LAT) on-board Fermi gamma-ray observatory near the Galactic Centre have been received a lot of attention. Proposed interpretations include dark matter annihilation [5–9], dark matter decay [9–11], systematic effects [2–4] and an astrophysical mechanism – comptonization (in deep Klein-Nishina regime) of cold ultra-relativistic e^+e^- pulsar wind by external UV/X-ray emission [1].

In this paper, we discuss the astrophysical mechanism proposed by [1] in more details. We show that, in addition to ~ 100 GeV line emission, it should produce broad γ -ray component due to comptonization of cosmic microwave background (CMB) radiation. For ~ 100 GeV astrophysical lines, the typical energy of this component should be several tens of MeV. Further detection of unidentified MeV sources with positions coinciding with GeV line excesses (such as GRO J1823-12 [12], located very close to 105-120 GeV excess (Reg. 1 of [2])) will argue in favour of the astrophysical origin of GeV lines.

II. MODEL DESCRIPTION

The model of [1] is based on inverse Compton scattering of energetic (UV and X-ray) photons by a cold ultra-relativistic e^+e^- pulsar wind accelerated in the vicinity of pulsar magnetosphere, see e.g. [13] for details. In this case, the scattering occurs in deep Klein-Nishina regime where the typical energy of the scattered photon is close to that of initial electron. If conversion efficiency is large enough, the mechanism of [1] can produce narrow ~ 100 GeV lines with flux $F_{line} \sim 10^{-10}$ erg cm $^{-2}$ s $^{-1}$, consistent with Fermi/LAT observations. Given the distance to Galactic centre ~ 8 kpc [14], such flux corresponds to luminosity $\sim 10^{36}$ erg/s.

In this paper, we assume the validity of the model proposed in [1]. In this case, one should also detect the softer continuum component due to Compton scattering of CMB radiation on e^+e^- wind. In Thomson regime, the average energy of the scattered CMB photons is ¹ [15]

$$\langle \epsilon_1 \rangle = \frac{4}{3} \gamma^2 \langle \epsilon_{\text{CMB}} \rangle \approx 34 \left(\frac{\gamma}{2 \times 10^5} \right)^2 \text{ MeV}, \quad (1)$$

where $\gamma \sim 2 \times 10^5$ is the Lorentz factor of cold electron-positron wind (able to produce ~ 100 GeV photon line [1]), $\langle \epsilon_{\text{CMB}} \rangle \approx 2.7 T_{\text{CMB}} = 6.3 \times 10^{-4}$ eV is the average energy of CMB photons. Total flux of this softer component equals to

$$F_{\text{soft}} = F_{\text{line}} \times \frac{(dE/dt)_{\text{T}}}{(dE/dt)_{\text{dKN}}}, \quad (2)$$

¹ Throughout this paper, we use notations from [15].

where $(dE/dt)_T$ and $(dE/dt)_{dKN}$ are the average energy loss rates of a single e^- or e^+ in Thomson and deep Klein-Nishina regimes, respectively. To calculate $(dE/dt)_T$ and $(dE/dt)_{dKN}$, we use expressions (2.18) and (2.57) from [15]:

$$(dE/dt)_T = -\frac{4}{3}\sigma_T c \gamma^2 \mathcal{E}_{CMB}, \quad (3)$$

$$(dE/dt)_{dKN} = -\frac{3}{8}\sigma_T m_e^2 c^5 \times \int \frac{n_{\text{ext}}(\epsilon) d\epsilon}{\epsilon} \left[\ln \left(\frac{4\epsilon\gamma}{m_e c^2} \right) - \frac{11}{6} \right]. \quad (4)$$

Here, σ_T is the Thomson cross-section, $\mathcal{E}_{CMB} \approx 0.26$ eV/cm³ is the CMB energy density, $n_{\text{ext}}(\epsilon)$ is the density distribution of external radiation leading to production of ~ 100 GeV lines.

According to [1], to explain the smallness of measured width of ~ 100 GeV lines, the energy of external photons should be high enough,

$$\epsilon \gtrsim \epsilon_{\text{min}} = 20 \left(\frac{\gamma}{2 \times 10^5} \right)^{-1} \text{ eV}, \quad (5)$$

to ensure that the corresponding Compton scattering occurs in the deep Klein-Nishina regime. [1] proposes two possible origins of external emission with such an energy:

- thermal emission from the surface of the neutron star;
- thermal emission from the hot companion star (in case of binary pulsar).

In both cases, the density distribution of external radiation can be approximated with that of rescaled blackbody radiation:

$$n_{\text{ext}}(\epsilon) = \frac{15\mathcal{E}_{\text{ext}}}{\pi^4 T_{\text{ext}}^4} \frac{\epsilon^2}{\exp(\epsilon/T_{\text{ext}}) - 1}, \quad (6)$$

where \mathcal{E}_{ext} and T_{ext} are the total energy density and temperature of external radiation. Substituting (6) into (4), we obtain in accordance with expression (2.59) of [15],

$$(dE/dt)_{dKN} = -\frac{15}{16\pi^2} \sigma_T c \gamma^2 \mathcal{E}_{\text{ext}} \mathcal{F} \left(\frac{\gamma T_{\text{ext}}}{m_e c^2} \right), \quad (7)$$

where

$$\mathcal{F}(x) = \frac{1}{x^2} \left[\ln(4x) - \frac{5}{6} - C_E - C_l \right], \quad x \gg 1,$$

$C_E \approx 0.5772$ is the Euler's constant,

$$C_l = \frac{6}{\pi^2} \sum_{k=2}^{\infty} \frac{\ln k}{k^2} \approx 0.5700.$$

Substituting (3) and (7) to (2), we obtain

$$F_{\text{soft}} = F_{\text{line}} \times \frac{64\pi^2}{45} \frac{\mathcal{E}_{CMB}}{\mathcal{E}_{\text{ext}} \mathcal{F} \left(\frac{\gamma T_{\text{ext}}}{m_e c^2} \right)}. \quad (8)$$

The ranges for function \mathcal{F} can be obtained from numerical estimates of T_{ext} . For neutron stars, $T_{\text{ext}} \lesssim 1$ keV, see e.g. [16], so $\mathcal{F} \gtrsim 4 \times 10^{-5}$. On the other hand, for small T_{ext} function \mathcal{F} has a maximum, $\mathcal{F} \lesssim 0.0560$. For these values of \mathcal{F} , we obtain the following relation between \mathcal{E}_{ext} , F_{soft} and F_{line} :

$$65 \text{ eV/cm}^3 \lesssim \mathcal{E}_{\text{ext}} \frac{F_{\text{soft}}}{F_{\text{line}}} \lesssim 9 \times 10^4 \text{ eV/cm}^3. \quad (9)$$

To calculate F_{soft} , we use CGRO/COMPTEL observations of GeV line sources in MeV band. Interestingly, one of the detected CGRO/COMPTEL sources, GRO J1823-12 [12] (see also 3EG J1823-1314 [17]), is located very

close to Reg. 1 of [2], where the $\sim 4.7\sigma$ excess at 105-120 GeV has been found [2]. The flux from GRO J1823-12 in 10-30 MeV band is $(1.0 \pm 0.2) \times 10^{-5}$ photon $\text{cm}^{-2} \text{s}^{-1}$ [12], the corresponding flux from 3EG J1823-1314 is $(2.7 \pm 0.5) \times 10^{-5}$ photon $\text{cm}^{-2} \text{s}^{-1}$ [17], which gives us the estimate for F_{soft} detectable with CGRO/COMPTEL near the Galactic Centre region

$$F_{soft} \simeq (10^{-10} - 10^{-9}) \text{ erg cm}^{-2} \text{s}^{-1}.$$

To detect softer component from ~ 100 GeV line emitter candidates (with $F_{line} \sim 10^{-10}$ erg $\text{cm}^{-2} \text{s}^{-1}$) with CGRO/COMPTEL, the value of \mathcal{E}_{ext} should be in the range

$$10 \text{ eV/cm}^3 \lesssim \mathcal{E}_{ext} \lesssim 10^5 \text{ eV/cm}^3. \quad (10)$$

These values of \mathcal{E}_{ext} are expected for Galactic Ridge region [18, 19].

III. CONCLUSIONS

We showed that the astrophysical mechanism of ~ 100 GeV line production proposed by [1] leads to presence of additional softer broadened component originated from inverse Compton scattering of CMB radiation by cold ultrarelativistic electron-positron wind. The typical energy of the softer component should be around 30 MeV and can it thus be detected by MeV telescopes such as CGRO/COMPTEL.

Further identification of this component with instruments operating in MeV band may lead to confirmation of astrophysical origin of the ~ 100 GeV line(s).

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